# ANALYSIS OF LAND EROSION ATTRIBUTES IN U.S. ARMY LAND CONDITION TREND ANALYSIS (LCTA) DATA, FORT CARSON, COLORADO

by
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in U.S. Army Land Condition Trend Analysis (LCTA) Data
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## Introduction

### Land Condition Trend Analysis

Until the mid-1980s the Department of Defense (DOD) and the U.S. Army tended to ignore many environmental requirements because of overriding considerations for national security. Since that time DOD and their member services have initiated an ecological monitoring system called Land Condition Trend Analysis (LCTA). LCTA is designed to inventory vegetation and soil resources, to classify lands as to the kind and amount of use they can support, and to monitor the type and degree of use they receive (Warren, Diersing, Thompson and Goran 1989).

Military commanders are concerned about off-site erosion from their lands resulting from training activities. Thus, disturbance indicators and evidence of soil erosion are important components of the LCTA data base (Tazik et al. 1992). This paper describes a screening of LCTA data for one Army installation, the Fort Carson Military Reservation, in order to determine the relationship between erosion and various physiographic and land use factors. This study will be a precursor to future work into relationships between LCTA monitoring and detecting and predicting soil erosion on military lands.

### Fort Carson Military Reservation

Fort Carson is located in south-central Colorado at the foot of the Rocky Mountain Front Range. Fort Carson comprises approximately 136,000 acres. The primary mission of Fort Carson is to train the 4th Infantry Division in mechanized armored warfare (Linn and Gordon 1992).

Three mountainous areas with elevations above 1960 meters are located within Fort Carson. The installation is defined by three vegetative physiographic regions: grasslands, shrublands, and forests and woodlands. Grasslands comprise approximately 70 percent of the vegetation (Gordon 1989).

Previous Research

The effect of off-highway traffic on soil compaction and environmental damage has been investigated by many researchers. Soil compaction and disturbance resulting from traffic of off-highway vehicles can cause environmental damage by decreasing plant development and increasing erosion (Shaw and Diersing 1989). The vegetation loss and increased erosion on land subjected to armored vehicle training is of recent concern (Ayers, Diersing, Shaw and Riper 1990). A study by Prose (1985) found that soil compaction resulting from armored military maneuvers has lead to retarded vegetation growth and accelerated erosion although the activities ceased for a 40-year period.

Much of Fort Carson is available for tracked vehicle training, primarily tanks and armored personnel carriers. Diersing, Shaw, Warren and Novak (1988), in estimating allowable use levels of tracked vehicles at the Pinon Canyon Maneuver Site in southeastern Colorado, reported that passage of tracked vehicles over the land disaggregates and compacts the soil, crushed herbaceous and woody vegetation, and exposes the soil to the erosive forces of rain and overland flow. If vegetative loss is excessive, serious soil erosion may occur in a few years, leaving the land gullied and unusable for future training exercises.

The effects of military tracked vehicle maneuvers on the vegetation of the Pinon Canyon Maneuver Site were assessed in detail by Shaw and Diersing (1990). Tracking was found to significantly decrease vegetational ground cover (live and litter) and increase the percentage of bare ground.

Soil erosion is a function of several variables, including slope length and steepness, soil physical properties, and the type and amount of various soil covers (e.g., plants, rock, duff, litter). Regardless of type, the amount of cover (or lack thereof) provides a rough estimate of the degree of erosion protection afforded to the soil.

Universal Soil Loss Equation

Much of the data acquired from LCTA field plots was collected in a format that would facilitate its incorporation into the Universal Soil Loss Equation (USLE). The USLE was developed to predict average rates of soil loss on agricultural lands from sheet and rill erosion by water. The USLE has been modified to predict erosion more accurately on non-agricultural lands, including rangelands (Smith et al. 1984, Renard et al. 1991). The Revised Universal Soil Loss Equation (RUSLE) furnishes an estimate of the average annual erosion from a field area. It is expressed by the equation:

$$A = R \times K \times L \times S \times C \times P$$

where A = computed soil loss per unit area, R = a rainfall and runoff coefficient, K = soil erodibility factor, L&S = topographic terms representing slope length and steepness, C = cover-management factor, and P = support practice factor.

Research Objectives

It was not an objective of this research to calculate soil loss along LCTA field plots at Fort Carson. Rather, a data screening was desired in order to determine the extent of disturbance and erosion data, and to ascertain whether LCTA data can be used to detect relationships between these variables and physiographic and soil measures. Specifically, the objectives of this research were to:

1. Describe the frequency of accelerated wind and water erosion noted on plots at Fort Carson, and

2. Describe the statistical relationships between wind/water erosion and soils and other physiographic factors.

# Methods

Data Set

LCTA data gathered in 1989 at Fort Carson were used in the analysis. Two hundred and three permanent LCTA vegetation plots had been established on the installation during the 1989 field season (August through November). Each plot is a 100-meter transect in which 100 points are sampled. Data from field plots were entered into hand-held computers by field crews, and then downloaded into an ASCII-formatted data base.

There are 203 field plots that cover both disturbed and non-disturbed land use classes within Fort Carson. Along each plot the following independent variables relevant to this study were recorded: land use and disturbance (from a range of military and non-military uses) ground cover, slope length and gradient, and soil factors related to erosivity (texture and organic matter). Evidence of wind and water erosion was chosen as the dependent variable for this data set.

Erosion Variable

The erosion variable was classified as follows:

| **Wind Erosion** | **Water Erosion** |
|---|---|
| None | None |
| Drifting | Sheet/Rill |
| Scouring | Active Gully |
| Pedestal Plant | Pedestal Plant |
| | Debris Dams |

Thus, measurement of erosion was at the nominal level. It should be noted that any given plot would contain at least two of these erosion categories: no evidence of wind erosion, and no evidence of water erosion. Further, a maximum of seven erosion categories could be recorded for any given plot since each type of wind and water erosion could be present at a site.

In order to determine the relative frequency of occurrence of the various erosion indicators in the data set, plots were classified as those having:

- No erosion indicators at all,
- Wind indicators only,
- Water indicators only,
- Both wind and water indicators, and
- Gullying only.

Groundcover Variables

Ground cover measurements and evidence of physical disturbance were recorded via the line-point method (Bonham 1989) at 1-meter intervals along each 100-meter transect. Ground cover categories in the Fort Carson LCTA data set include: bare ground, duff, deadwood, forb, gravel, litter, rock, shrub, and tree. The amount of bare ground was determined to be the best overall indicator of erosion, and was summed for each plot, yielding percent bare ground.

Disturbance Variables

The ground cover file also contain information on disturbance categories. LCTA disturbance categories include:

- None,
- Pass (a random vehicle track),
- Road (permanent or semi-permanent traffic route receiving periodic maintenance),
- Trail (semi-permanent traffic route receiving no maintenance) and
- Other (non-vehicular disturbances to soils such as excavation, bivouac activity, demolition, etc).

The data set was screened for any relationships between the degree of these point-level disturbances (i.e., percentage noted for each disturbance variable per plot) and the transect-level erosion indicators. This task was accomplished with the use of various tests of association.

Land Use Variables

A qualitative evaluation of military use, activities and evidence of wind and water erosion was made in the field for each permanent plot (Tazik et al. 1992). Disturbance noted on LCTA plots were collected under the following categories:

| **Military Land Uses** | **Non-Military Activities** |
|---|---|
| None | None |
| Wheeled | Grazing |
| Tracked | Row Crop |
| Foot | Forestry |
| Excavation | Hay |
| Bivouac | Other |
| Demolition | |
| Other | |

Since the location of military or non-military uses along each plot were not recorded as part of LCTA data collection, and since the only significant type of non-military activity noted within the Fort Carson LCTA data set was grazing by wildlife (which can not be correlated directly with erosion) the classifications of No Military Use, Military Use, and Grazing/Other were used in this analysis. That is, given the method with which the LCTA data were collected, one could not correlate, for example, whether wheeled or tracked vehicles contributed to the presence of erosion on a given plot (in the case where both were present). Such a distinction could only be made if just one type of land use were recorded.

Maintenance Variables

Maintenance activities identified in Fort Carson LCTA data were classified as: None, Burned (either prescribed or accidental), Seeded, and Other. These variables were therefore designated as nominal data in the analysis.

Slope Variables

Slope length and gradient were measured in the field at the zero, 50, and 100-meter points along each plot. Slope length is the straight-line distance runoff travels across each sample point. It is measured from the point of origin of runoff to a point where a barrier or

significant reduction in slope causes overland flow to be diverted into a channel or causes suspended sediment to be deposited (Tazik, Warren, Diersing, Shaw, Brozka, Bagely and Witworth 1992). Slope gradient was measured with a clinometer to the nearest half percent.

Since measurements for erosion, land use and disturbance were nominal (i.e., either present or not present), a single value for slope length and gradient was desired in order to best pair these data sets. Therefore, the maximum value of slope gradient, and its corresponding slope length, was used for each plot since it was assumed that erosion, if present along a given plot, would be present on steeper slopes. Assumptions such as this are necessary since erosion is noted only as being present along a given plot; the exact location of where erosion occurs was not recorded as part of LCTA field data.

Soil Variables

Two soil samples were collected from each of the 203 core plots. As part of the LCTA data collection, samples were sent to the National Soil Survey Laboratory in Lincoln, Nebraska, for textural class analysis, soil pH, and organic carbon. Units of measurement of textural class and pH were intended to be incorporated into the Revised Universal Soil Loss Equation (RUSLE) which is an empirically-derived conservation planning guide for soil loss (Renard et al. 1991). Each variable in the RUSLE is represented as a dimensionless coefficient that varies according to its deviance from an empirical standard. Soil erosivity (K) in the RUSLE is estimated as a function of a sample's textural class (total clay, total silt, and very find sand) and organic matter content (OM), so that:

$$K=2.1 \times 10^{-6} \times (((TotSilt+VfSand) \times (100-TotClay))^{1.14}) \times (12-OM)$$

Note: The coefficients for soil structural code and permeability class have been omitted from the above equation for the purposes of simplification and were not used in this analysis.

Mean values of each of these parameters were used in this data analysis. Thus, means were determined for total clay, total silt, very find sand, and organic matter for each plot, and these values were incorporated into the USLE in order to arrive at a single variable that

represented a plot's erosivity.

Statistical Analysis

All data analysis was performed with the aid of SAS computer software for PCs (SAS Institute, Inc. 1988). The method of discriminant analysis was initially used to evaluate the relationship between erosion and the independent variables. This was done by dividing the data set into two populations: 1) those plots that did not contain indicators or erosion, and 2) those plots that contained erosion indicators.

Discriminant analysis is used to determine how one or more independent variables can be used to discriminate among different categories of a nominal dependent variable (Kleinbaum and Kupper 1978). This method, like regression analysis, allows the researcher to determine and rank important variables that can distinguish transects that contain signs of erosion and those that do not. With this method the researcher can also obtain an equation (called a logistic function) which provides an estimate of the probability that a transect with a given set of attributes will contain indicators of erosion.

Alternative statistical methods were considered for application in the case that the initial analysis failed to discriminate between the two populations under study. These alternative methods included principal component analysis and logistic regression.

## Results

Frequency Data

The following information relevant to the interpretation of LCTA erosion data is taken from Gordon's (1989) *Land Condition/Trend Analysis Installation Report: Fort Carson Military Reservation, Colorado.*

Only 199 of the 203 core plots established on the FCMR were available for military use. Ninety-one percent (182) of the 199 plots showed some type of military land use based on a qualitative presence/absence inventory. The primary military use was by wheeled (86%) and tracked (84%) vehicles. Evidence of foot use occurred on 28% of the plots. Seventeen plots (9%) showed no evidence of military use.

Thirty-six percent of the 19,900 (199 plots available for military use X 100 points per transect) points surveyed showed signs of military use in the form of passes, trails, roads, and other disturbances. Ninety-four percent (n = 6736) of such use were in the form of passes (a pass if defined as a random vehicle track which does not follow an established traffic pattern).

Ninety percent of the plots inventoried showed signs, primarily sheet and rill, of water erosion. Seventy-seven percent of the plots showed signs of wind erosion. The greatest occurrence of erosion was on transects which had been disturbed by wheeled and tracked vehicles.

Thus, of the 203 LCTA plots at Fort Carson, approximately nine percent (n = 19) contained no indicators (either wind or water) of erosion. None of the 203 plots contained indicators solely of either wind or water erosion (see Table 1). Only one plot contained evidence of gullying only. For the purposes of discriminant analysis, the single plot with evidence of gullying only was added to the wind/water/both indicators category, leaving the dependent variable as belonging to either one of two possible populations: those plots with no erosion indicators, and those with wind/water/both indicators (see Table 2).

<u>Association of Disturbance and Erosion</u>

Given the high occurrence of the disturbance variable "Pass" for all plots, tests of association were performed to determine if, based on the type of erosion present, there is a significant difference between those plots that contained evidence of a "Pass" and those that did not. As shown in Table 3, each test revealed a significant difference ($p < 0.1$) between the two populations, indicating that there is an association between the presence of a "Pass" and indicators of erosion. Figure 1 depicts the degree to which "Pass" was noted on each of the 203 LCTA plots.

*TABLE 3*
*Relationship Between PASS and EROSION Variables Per Plot*

| EROSION VARIABLE | PASS VARIABLE | | |
|---|---|---|---|
| Frequency/ Percent | Plots without "Pass" | Plots with "Pass" | Total |
| No Erosion | 9<br>4.43 | 10<br>4.93 | 19<br>9.36 |
| Wind/Water Erosion | 42<br>20.69 | 141<br>69.46 | 183<br>90.15 |
| Gullying Only | 0<br>0.0 | 1<br>0.49 | 1<br>0.49 |
| **Total** | **51**<br>**25.12** | **152**<br>**74.88** | **203**<br>**100.00** |

| Statistic | DF | Value | Prob. |
|---|---|---|---|
| Chi-Square | 2 | 5.793 | 0.055 |
| Likelihood Ratio Chi-Square | 2 | 5.411 | 0.067 |
| Mantel-Haenszel Chi-Square | 1 | 5.763 | 0.016 |

Thus, in all cases, there is a significant ($p < .10$) difference between the two populations.

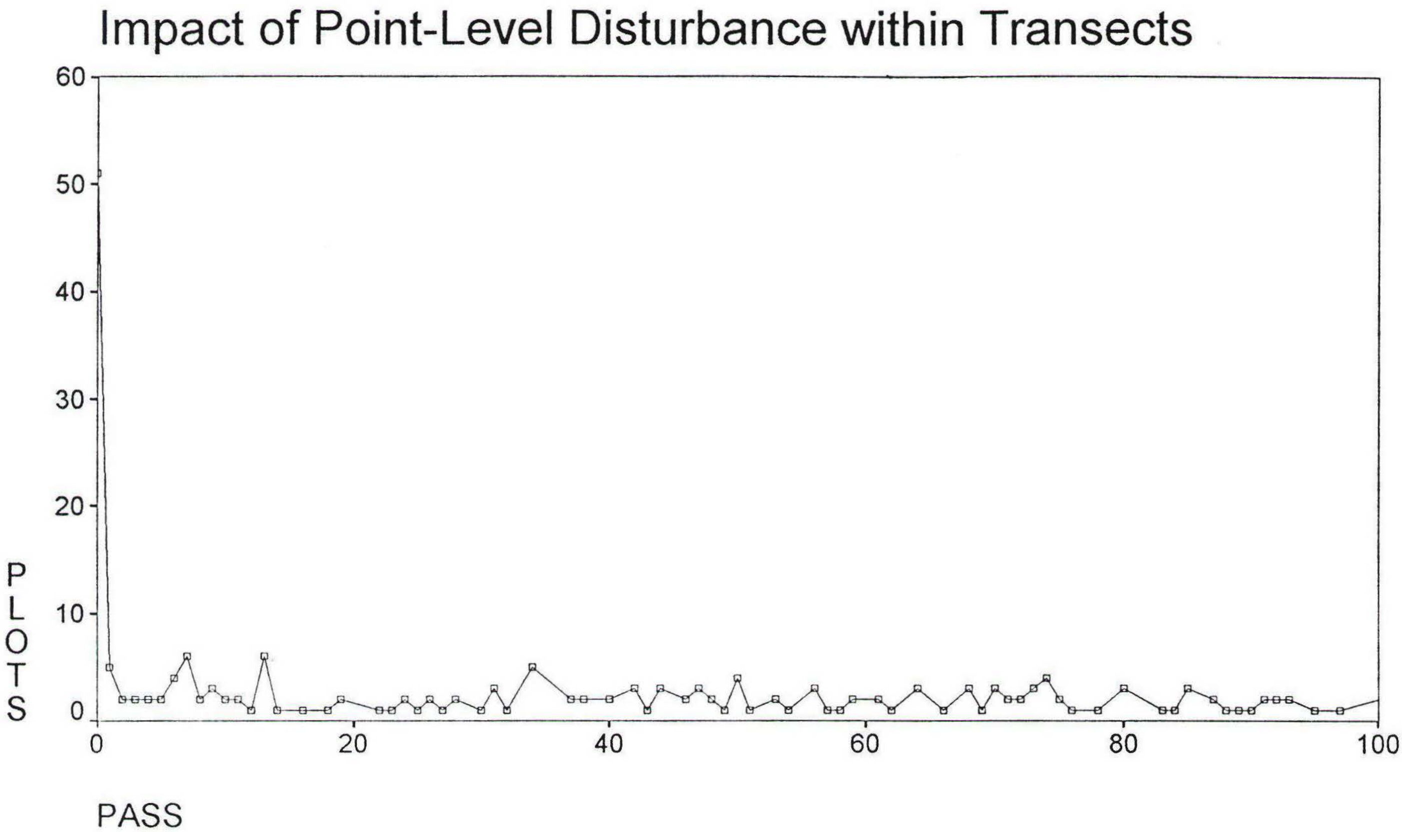
*TABLE 4*
*Groupings of Independent Variables used in the Discriminant Analysis Procedure*

| **Variables Used** (per plot) | **Cases with Erosion Correctly Classified** |
|---|---|
| Slope steepness, slope length, maintenance (none, burned, seeded, other), RUSLE K, %bare ground, and disturbance (%none, %pass, %road, %trail, %other) | 22.22% (n = 4) |
| Slope steepness, slope length, maintenance (none, burned, seeded, other), RUSLE K, and %bare ground | 16.76% (n = 3) |
| Slope steepness, slope length, RUSLE K, %bare ground, and disturbance (%none, %pass, %road, %trail, %other) | 15.79% (n= 3) |

*TABLE 5*
*Summary of Logistic Stepwise Procedure*

| Step | Variable Entered | Chi-Square | Pr. > Chi-Square |
|---|---|---|---|
| 1 | Percent Bare Ground | 16.8152 | 0.0001 |
| 2 | Slope Steepness | 6.5736 | 0.0104 |
| 3 | Percent Pass | 3.0322 | 0.0816 |

Note: No additional variables met the 0.1 significance level for entry into the model.


Impact of Point-Level Disturbance within Transects
PLOTS
PASS
0
10
20
30
40
50
60
0
20
40
60
80
100

Discriminant Functions

Several discriminant analysis procedures were performed in an attempt to evaluate the relationship between erosion and the various independent variables (see Table 2). Plots were thus assigned to separate populations based on whether or not they contained indicators of erosion. Table 4 shows the three separate groupings of independent variables used in the discriminant analysis procedure. In all three cases the discriminate function failed to identify important variables that distinguish plots with erosion from those that contain no signs of erosion. The inability to discriminate between the two populations is likely a result of the collinearity of the independent variables (i.e., they are likely highly correlated).

To eliminate the correlations that could exist between the independent variables, a principal component analysis was performed to determine the groups that might be used in a posterior discriminant analysis. However, the results of this procedure were similar to those in the original discriminant analysis, and failed to identify key independent variables that could be used to explain differences between the two study populations.

A logistic regression model was then attempted which utilized a stepwise procedure. With this analysis, the logit function could be explained by its relationship to the percentage of bare ground, slope steepness, and the percentage of "Pass" per plot (with 86.7% of the data set being accurately classified). All three variables were significant ($p < 0.1$) in the model, with the most important variable being percent bare ground (see Table 5). Therefore, if given these three variables, it is then possible to estimate the probability that a given plot contains no indicators of erosion with the equation:

$$\log (P/1-P) = 1.0878 - 0.083(\%\text{Slope}) - 10.2585(\%\text{Bare Ground}) - 2.8545(\%\text{Pass})$$

## Discussion

Evidence of intensive military use and widespread signs of erosion are clearly evident in the Fort Carson LCTA data base; the preponderance of such use being in the form of random vehicle tracks. Tests of association identified that there is a significant difference between those plots that contained evidence of random vehicle passes and those that did not in terms of whether erosion was present (see Table 3). It can therefore be concluded that evidence of erosion can be explained, in part, by the presence of random vehicle passes at Fort Carson. This conclusion is not only intuitive, but is supported by the data.

It would appear that discriminant analysis is not the appropriate tool to determine how independent variables can be used to discriminate between the two erosion populations derrived from the Fort Carson LCTA data set. As described in the preceding Results section, the inability to discriminate between the two populations is likely a result of the high correlation between the independent variables. The only way to possibly weaken this correlation is by adding more independent variables. That is, additional data (e.g., wind speed, or a surface roughness coefficient) would need to be added to the analysis.

It was only through the use of the logit function, however, that a relationship between some of the independent variables and the absence of erosion could be explained. Percentage of bare ground, slope steepness, and the percentage of "Pass," per plot, created an 86.7% probability that these variables could accurately predict lack of erosion for a given plot. It is therefore possible, based on these three variables and the equation given in the Results section, to estimate the probability that a given plot within the Fort Carson LCTA data set contains no indicators of erosion.

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*TABLE 1*
*Frequency Distribution of Transect-Level Erosion Per Plot*

| Indicator | Frequency | Percent | Cumulative Frequency | Cumulative Percent |
|---|---|---|---|---|
| No Indicators | 19 | 9.4 | 19 | 9.4 |
| Wind Only | 0 | 0.0 | 19 | 9.4 |
| Water Only | 0 | 0.0 | 19 | 9.4 |
| Wind/Water | 183 | 90.1 | 202 | 99.5 |
| Gully Only | 1 | 0.5 | 203 | 100.0 |

*TABLE 2*
*Variables Used for Fort Carson LCTA Data Statistical Analysis*

| Variable | Data Type |
|---|---|
| DEPENDENT | |
| **Erosion** | **Nominal** |
| No Indicators | |
| Wind/Water/Both Indicators | |
| INDEPENDENT | |
| **Land Use** | **Nominal** |
| No Military Use | |
| Military Use | |
| Non-Military (Grazing/Other) | |
| **Maintenance** | **Nominal** |
| None | |
| Burned | |
| Seeded | |
| Other | |
| **Disturbance** | **Nominal** |
| None (percent noted per plot) | |
| Pass (percent noted per plot) | |
| Road (percent noted per plot) | |
| Trail (percent noted per plot) | |
| Other (percent noted per plot) | |
| **Groundcover** | **Ratio** |
| Percent Bare Ground | |
| **Slope Steepness** | **Ratio** |
| Percent Slope | |
| **Slope Length** | **Interval** |
| Length (in meters) | |
| **Soil Erosivity** | **Ratio** |
| RUSLE K-factor | |